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Press forming process of closed-profile automotive parts without flange

Yuji Yamasaki[a,]*, Kazuhiko Higai[b], Toyohisa Shinmiya[a]

[a]*JFE Steel Corporation, 1 Kokan-cho, Fukuyama, Hiroshima, 721-8510, JAPAN*
[b]*JFE Steel Corporation,1 Kawasaki-cho, Chuo-Ku, Chiba, 260-0835, JAPAN*

Abstract

Automobiles are required weight reduction and improvement of collision safety. Additionally, rigidity of vehicle bodies is important performance that affects driving stability. Collision safety and rigidity of vehicles are strongly affected by strength and rigidity of the structural components. Accordingly, they are made of high strength steel / ultra-high strength steel and have closed cross section shapes (closed-profiles). Conventional closed-profile components are currently assembled by spot welding of two press-formed parts. Flanges of press-formed parts are required for spot welding and inhibit weight reduction. In the present situation, a new forming method was developed for closed-profile parts without flanges. The developed method was constituted three forming processes by using conventional mechanical press machines. In the 1st process, a steel sheet was partially stretched for adjustment of the cross section length and formed folds at ridgeline positions of the final shape. In the 2nd process, the formed sheet in 1st process was bent by press forming. In the 3rd process, the formed sheet in 2nd process was closed to hexagonal cross section shape by side tools which were driven transversely by cams. And finally it was added compression in plain by the punch. Trial product by the developed forming method satisfied the target performances (bending and torsion rigidity and collision strength). Weight reduction ratio was 39% by optimization of the cress section shape and removing flanges.

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Keywords: Press-forming; Closed-profile; Automotive parts; Without flange; High strength steel sheet

* Corresponding author. Tel.: +81-84-945-3624; fax: +81-84-945-4059.
E-mail address: y-yamasaki@jfe-steel.co.jp

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1. Introduction

Lately automobiles are required weight reduction and improvement of collision safety. Aims of Weight reduction are resource saving and global environment protection. Because weight of automobiles affects to the quantity of fuel consumption and the quantity of exhaust gas directly. On the other hand, Collision safety standard becomes gradually stricter, because safer automobiles are demanded. Additionally, rigidity of a automobile is another important performance that affects the driving stability.

Collision safety and rigidity of the automobile are mainly determined by the strength and rigidity of the structural components of the auto body. Closed profile structures applied to automotive structural components for improvement of collision safety and rigidity. At the same time, High strength / Ultra-high strength steel sheets are used as material for structural components for improvement of collision safety.

A current closed profile structural component is consist of two press formed parts, and two parts are joined by spot welding. For the reason, the press formed parts are needed flanges for spot welding. Flanges cause increase of weight. In contrast, some forming methods of closed profile structural component which is consist of one part are developed. Closed profile structural components without flanges are able to be formed by hydroforming or roll forming etc..By hydroforming, three dimensional curved parts are able to be formed, but much longer forming time is needed than by press forming [1]. By roll forming, complex cross section shape are able to be formed, but three dimensional curved parts are not able to be formed. And these forming methods need unique equipment [2].

Under these circumstances, A new forming method of closed profile structural components without flanges by using conventional press machine was developed.

In this study, The forming method of a front side member was investigated as a case study. The investigation was carried out in following three steps. In the first, Cross section shape was optimized. Next, The front side member was manufacrured by way of trial. Finally, Collision strength of the prototype was evaluated.

2. Optimization of cross-section shape

Cross section shape strongly affects on performance, collision strength, bending and torsional rigidity, of the structural component. Therefore, simple removing of flanges causes performance deterioration of it. For this reason, the cross section shape was optimized to meet the requirement of collision strength, bending and torsional rigidity by CAE.

2.1. CAE conditions

The optimization of the cross section shape was performed as limited to rectangular and hexagonal without flange. Additionally, weight reduction by 980MPa 1.4mm thickness high strength steel sheet investigated.

As evaluation of collision strength, simulations of axial crash tests were carried out in following conditions and absorbed energy were calculated. Specimens had uniform cross section shape in longitudinal direction and 400mm length. They were collapsed 100mm at constant velocity of 10 m/s (36 km/hr) [3]. LS-DYNA (Livermore Software Technology Corp.) was used for FE analysis. Mesh size were 2.5 mm. Stress-strain parameters were identified from tensile test results at several tensile speeds. Other material parameters are 210GPa in Young's modulus, 7.85 x 103 kg/m3 in density and 0.3 in Poisson ratio.

As evaluation of bending and torsional rigidity, simulations of three-point bending tests and torsion tests were carried out in following conditions. Specimens had uniform cross section shape in longitudinal direction and 900 mm length. In three-point bending tests, they were supported at both ends and applied 2kN load to the center in longitudinal direction. In the torsion tests, they were fixed at an end of specimens and applied 1kN•m moment at another end of them. OptiStruct (Altair®) was used for FE analysis. Mesh size were 2.5 mm. Material parameters are 210GPa in Young's modulus, 7.85 x 103 kg/m3 in density and 0.3 in Poisson ratio.

2.2. Results of optimization

Structural parts such as front side members generally have a rectangular cross section shape with flanges as shown in Fig. 1(a). The reference cross section shape has 120mm x 80mm rectangular cross section shape and 5mm ridgeline radius with flanges and made of 590MPa 1.6mm thickness high strength steel sheet. Flanges are around 25 mm width for spot welding. The weight of flanges occupies about 20% of the total weight. Nevertheless, same size rectangular cross section shape without flanges had lower absorbed energy and bending stiffness than reference shape as shown in Fig. 1(b). The expanded rectangular cross section shape, which secured all performances equal to or more than reference shape, was same weight as reference shape as shown in Fig. 1(c). It had been already reported that polygonal cross section shapes, such as hexagon or octagon, have higher absorbed energy than rectangular cross section shape [4]. An example of a hexagonal cross section shape and its performances are shown in Fig. 1(d). It was 12% lighter, and had higher stiffness and absorbed energy than the reference cross section shape. Those results show that hexagonal cross section shape is effective in both weight reduction and performance improvement.

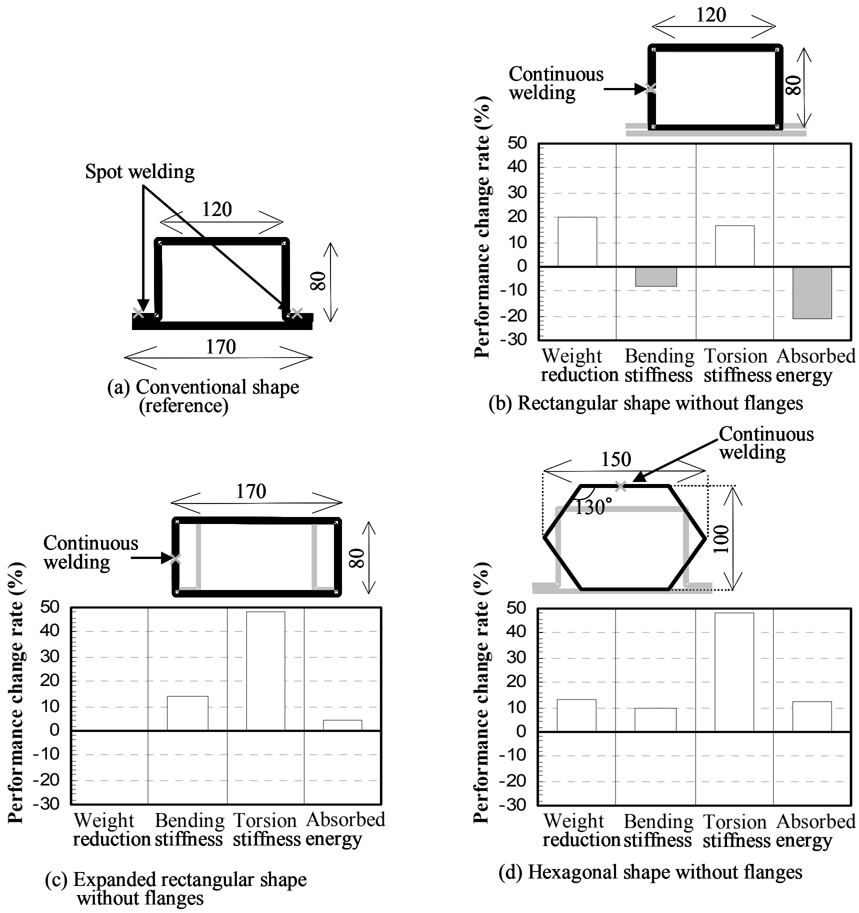


Fig. 1. Effect of the cross-section shape on properties of parts.

For the above results, a hexagonal cross section shape was selected and optimized. The reference cross section shape was determined by our benchmarking of front side members of commercial midsize automobiles as shown in

Fig. 2(a). The hexagonal cross section shape was optimized in the condition which has equivalent absorbed energy to the reference shape as shown in Fig. 2(b). Weight of the hexagonal cross section shape without flanges could be 40% reduced compared with the reference cross section shape.

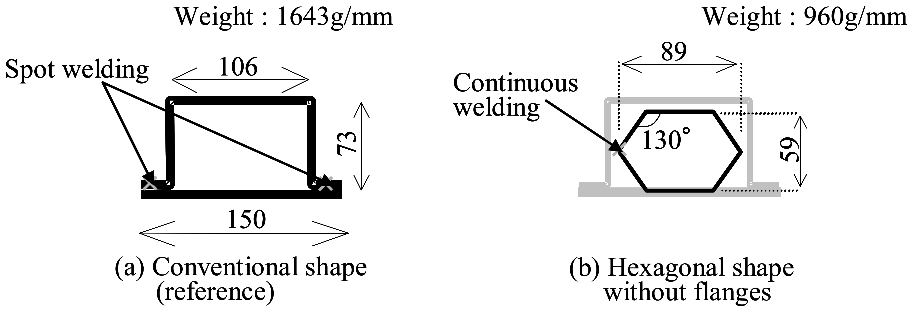


Fig. 2. Optimization of the hexagonal cross section shape.

3. Development of forming process for closed profile parts

Based on the above optimization result, the shape of the prototype was designed in a size of 1/2 of actual parts as shown in Fig. 3. It has a hexagonal cross section shape and has crush beads on the side wall of front side of a car as a starting point of axial collapse. 590 MPa 1.6 mm thickness and 980 MPa 1.2 mm thickness high strength steels were used for trial manufacture. A conventional 11,800 kN mechanical press machine was used. The developed forming method for closed profile parts is constituted of three forming processes as shown in Fig. 4.

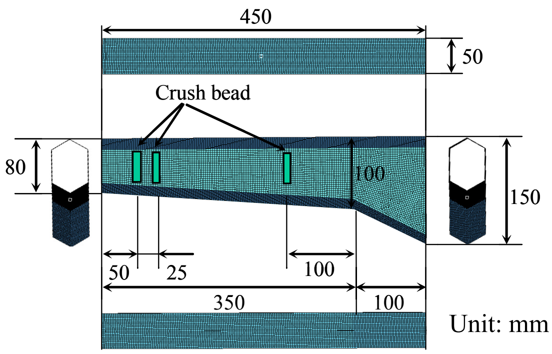


Fig. 3. Schematic diagram of front side member model.

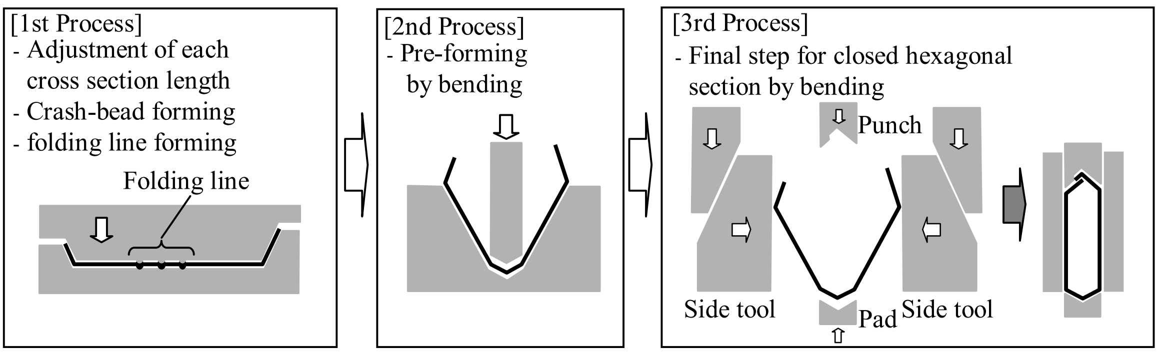


Fig. 4. Schematic diagrams of developed press forming process.

In the first process, partly stretch forming by stamping is carried out to have the same length as perimeter of the final shape at each cross section in longitudinal direction. Folds, which improve the dimensional accuracy of the formed part, are formed at ridgeline positions of the final shape. At the same time, crush beads are formed. In the second process, preliminary bending by stamping is carried out on the bottom of parts. In the third process, close forming is carried out. The vertical walls are pushed transversely to center direction by side tools which are driven by cams. And finally the formed part is added compression in plain by the punch.

Additionally, two temporary fixing methods in the forming process were developed to facilitate the continuous welding as shown in Fig. 5. By the overlap method, the formed part is temporarily fixed by hooking of overlap around 5 mm as shown in Fig 5(a). By the partial hemming method, the formed part is temporarily fixed by clinching of partial hemming as shown in Fig. 5(b).

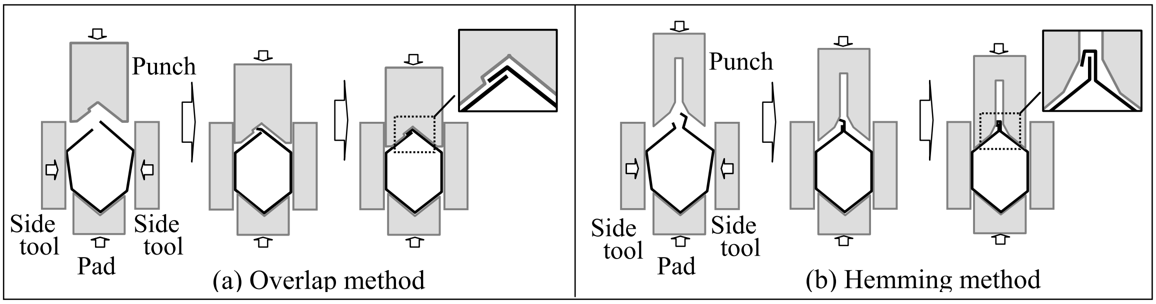
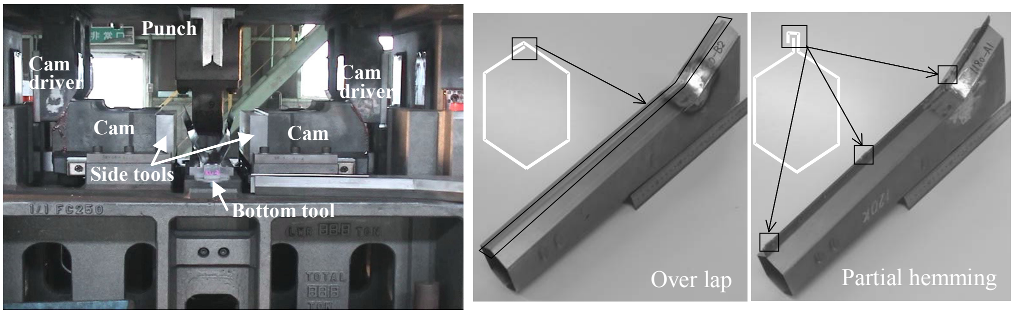


Fig. 5. Schematic diagrams of temporary fix methods and welding position.

Constructions of the forming die of the third process are shown in Fig. 6(a). It is consisted of the punch, bottom tool and side tools which are driven by cams. Formed prototypes which were temporary fixed by deferent fixing methods are shown in Fig. 6(b). Both prototypes were successfully formed to take the intended shape without a crack or a wrinkle.



(a) Constructions of the forming die (The third process)

(b) Formed parts

Fig. 6. Constructions of forming die and formed parts.

4. Evaluation of energy absorption of prototype parts

4.1. results of high-speed crash test

The results of high-speed crash test are shown added the simulation results in Fig. 7. The prototype parts were made of 590MPa 1.6 mm thickness or 980MPa 1.2 mm thickness high strength steel and closed by continuous laser welding. And the reference part is made of 590MPa 1.6 mm thickness high strength steel and joined by spot welding. Absorbed energies were compared among the prototype parts and reference part. The prototype parts which were made of 590MPa 1.6 mm thickness or 980MPa 1.2 mm thickness high strength steel had similar absorbed energy to the reference part. As the results, the effect of weight reduction by optimization of the hexagonal cross section shape and removing flanges was estimated 39%. If similar cross section part was manufactured by conventional press forming method, it would be needed flanges for spot welding. It causes 12% weight increase. On the other hand, the effect of weight reduction by using a 400MPa higher material and thickness reduction was estimated 18%.

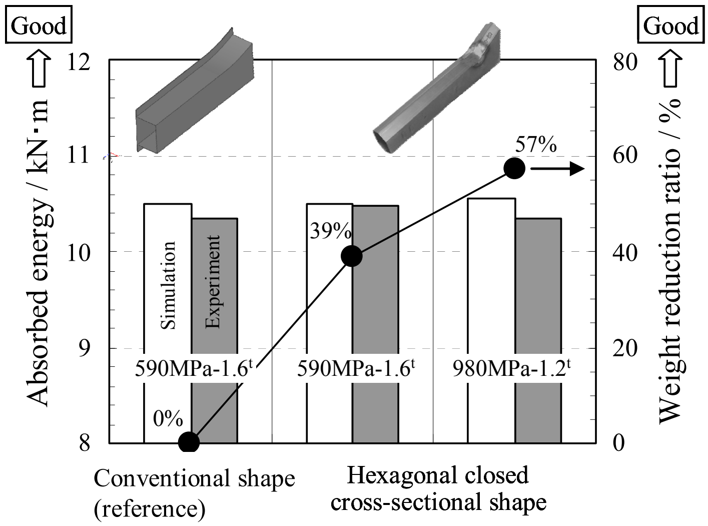


Fig. 7. Absorption energy and weight reduction ratio of front side member model.

5. Conclusions

A new forming method of closed profile structural components without flanges was studied. A front side member was produced experimentally by the method. Collision strength of the prototypes were evaluated. The conclusions reached were follows :

(1) A front side member which had closed profile without flanges can be formed by the developed forming process by using a conventional press machine.
(2) Additionally, temporary fixing methods in the forming process were developed to facilitate the continuous welding.
(3) The effect of weight reduction ratio by optimization of the hexagonal cross section shape without flanges was estimated 39% in case of the front side member.
(4) The effect of weight reduction ratio by thinning the 400MPa higher strength steel sheet was estimated 18% in case of the front side member.

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